

NASA Contractor Report 172371

Flight Service Evaluation of Two Aluminum-Brazed Titanium Spoilers

R. R. Boyer

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**Boeing Commercial Airplane Company
Seattle, Washington**

August 1984

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**Prepared for
Langley Research Center
under Contract NAS1-13897**

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National Aeronautics and
Space Administration

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N84-31343#

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1.0 SUMMARY

The objective of this program was to confirm laboratory results indicating that aluminum-brazed titanium (ABTi) structure has corrosion resistance suitable for aerospace structural applications. To accomplish this objective, two ABTi honeycomb spoilers were flown on All Nippon Airways Model 737 airplanes for approximately 8 years. A spoiler was selected for this program because it was felt that the design and manufacturing problems it presented would be representative of any difficulties that would be encountered in producing wedge-type shapes and in introducing point loads into honeycomb structure. A Japanese airline was selected for flight service evaluation because Japan has one of the most severe marine-industrial environments in the world. This program allowed accurate assessment of the effects of flight and ground loading in conjunction with environmental effects on ABTi flight structure in commercial service.

Before delivery of the spoilers to All Nippon Airways, two additional spoilers were built. The first, a preliminary design test part, was used to assess the design, particularly in the area of the fittings, and to test the braze tooling. The second part was tested to the design limit load, fatigue tested for 300,000 cycles, and again loaded to the design limit load to obtain FAA certification.

This program demonstrated the viability of ABTi structure for airframe applications. The ABTi structure showed no signs of degradation in structural integrity at the conclusion of flight testing and after imposition of 100% design limit load, even though there was a sizable manufacturing defect in one of the spoilers. Smaller voids were also detected, some of which showed some apparent growth during flight service as evidenced by ultra-sonic C-scans. Destructive inspection, however, indicated that these were also manufacturing defects, and there was no evidence to indicate that these defects increased in size during flight testing.

2.0 INTRODUCTION

Aluminum-brazed titanium (ABTi) honeycomb sandwich is an attractive aerospace structural material because of its relatively low structural density and high stiffness. Initially, there was concern about the corrosion resistance of the ABTi system because of the electrochemical potential difference between aluminum and titanium. This concern was shown to be unfounded in a number of studies (refs. 1-4.). The good corrosion resistance is attributed to the tenacious oxide film that forms on the titanium and prevents activation of the electrolytic cell. The testing referenced above, however, was basically restricted to coupon testing.

This program was initiated to confirm the laboratory results by real-time commercial airline service experience. To accomplish this, two ABTi flight spoilers were fabricated and installed on All Nippon Airways Model 737 aircraft. The spoilers accumulated a total of 8 years of service experience. All Nippon Airways was selected because Japan has one of the most severe corrosion environments in the world. This program permitted a realistic assessment of the effects of flight and ground loading in conjunction with environmental effects on actual ABTi flight hardware structure. Two additional spoilers were built, a preliminary design test part and a flight configuration part, to obtain FAA flight certification and to prove the design concept.

The spoilers used for this program were built during the Department of Transportation Supersonic Transport (DOT-SST) follow-on program (refs. 5,6), which demonstrated the engineering and manufacturing practicality of producing typical ABTi honeycomb sandwich flight service components.

The spoilers were periodically inspected by Boeing during flight testing to ensure part integrity and to assess the rate of deterioration, if any. The spoilers were visually inspected on the airplane once a year. A pulse-echo ultrasonic C-scan was performed on each part after fabrication, at an intermediate stage in flight service, and at the end of flight testing. In addition, each flight spoiler was strain gaged and tested to the design limit load before installation. They were strain gaged and tested in the same manner after the flight service evaluation. These inspections and tests permitted a concise evaluation of the effects of flight service in a severe environment on ABTi flight hardware.

This report summarizes the program results and includes discussions of:

- Spoiler fabrication and design considerations
- Fatigue and proof testing required for FAA certification
- Proof loading of the flight spoilers before and after the service exposure
- Ultrasonic C-scan results before and after the service exposure
- An assessment of the applicability of ABTi on aircraft structure

3.0 SPOILER DEVELOPMENT AND VALIDATION

The 737 spoiler was selected for this program because it was felt that the manufacturing and design problems it presented would be representative of any difficulties that would be encountered in producing wedge-type shapes and in introducing point loads into honeycomb sandwich structure. The aluminum-brazed titanium (ABTi) spoiler design concept was based on an open-edge (nonsealed) panel with brazed-in load-transfer fittings. This approach, which uses faying-surface fitting-skin and fitting-core shear-tie brazements, required development to resolve the joining problems associated with load transfer from the core and skin to the fitting. The design iterations and tooling developments required to produce the final flight spoilers are discussed in detail in reference 5. The results of those efforts will be summarized here to provide a better picture of the overall program.

Four spoilers were fabricated. The first, a preliminary design test part, was used to assess the design of the fitting-skin-core brazements at the outboard hinge fittings and the center yoke and to test the braze tooling. This provided a starting point from which to design further tests and optimize the braze design in these critical areas. Following additional development testing, the geometry in the area of the outboard hinge fittings and the center yoke was finalized and three flight configuration spoilers were designed and fabricated. The second spoiler, a structural test part, validated the point design allowables and provided FAA certification. The third and fourth spoilers were mounted on All Nippon Airways Model 737 airplanes for flight service evaluation.

The ABTi spoilers consist of two tapered Ti-6Al-4V face sheets, with Ti-3Al-2.5V honeycomb core and machined Ti-6Al-4V center yoke and outboard hinge fittings. The lower sheet is 1 mm (0.040 in.) at the leading edge, tapering to 0.4 mm (0.016 in.) at the trailing edge. The upper sheet is 0.76 mm (0.030 in.) at the leading edge, also tapering to 0.4 mm (0.016 in.) at the trailing edge. The panel is made from 6.35-mm (0.25-in.) cell, 0.05-mm (0.002-in.) foil core (SC 4-20), with 3.18-mm (0.125-in.) cell, 0.05-mm (0.002-in.) foil core (SS 2-20) along the panel edges, as shown in Figure 1. The overall size is about 56 cm (22 in.) wide by 132 cm (52 in.) long. In addition, the original configuration, the preliminary design test part, had a faying-surface braze closeout at the trailing edge due to the difficulty of machining to very thin core heights. Ongoing core machining studies resulted in machining improvements that permitted use of a trailing-edge SS 2-20 core closeout. The core at the trailing edge of the final three spoilers tapers to 0.5 mm (0.020 in.) thick.

Fatigue testing of the preliminary design test part revealed a problem in the area of the fittings that required refinements in the center yoke and outboard hinge fitting designs to improve the faying-surface skin-fitting and core-fitting shear-tie brazements. Some additional component fatigue testing provided the necessary design improvements. The final center yoke fitting configuration is illustrated in Figure 2. The flanges of the Z-channel directed toward the center of the yoke are brazed to the upper face sheet (outer mold line skin) using spotweld gap control. The flanges of the Z-channel directed outward are nested in machined relief in the SS 2-20 core element surrounding the yoke and brazed with spotweld gap control to the lower face skin.

The outboard fitting tangs originally extended the full panel height, face skin to face skin. This did not cause any structural problems, but did cause a visible markoff on the spoiler face skins. The flight spoiler design was revised to provide 2.5-mm (0.10-in.) clearance from the edges of the tang to the face skins. After the outboard fitting was spliced to the core assembly for shear-ties, a narrow 2.5-mm (0.10-in.) segment of SS 2-20 core was spliced to the core blanket above and below

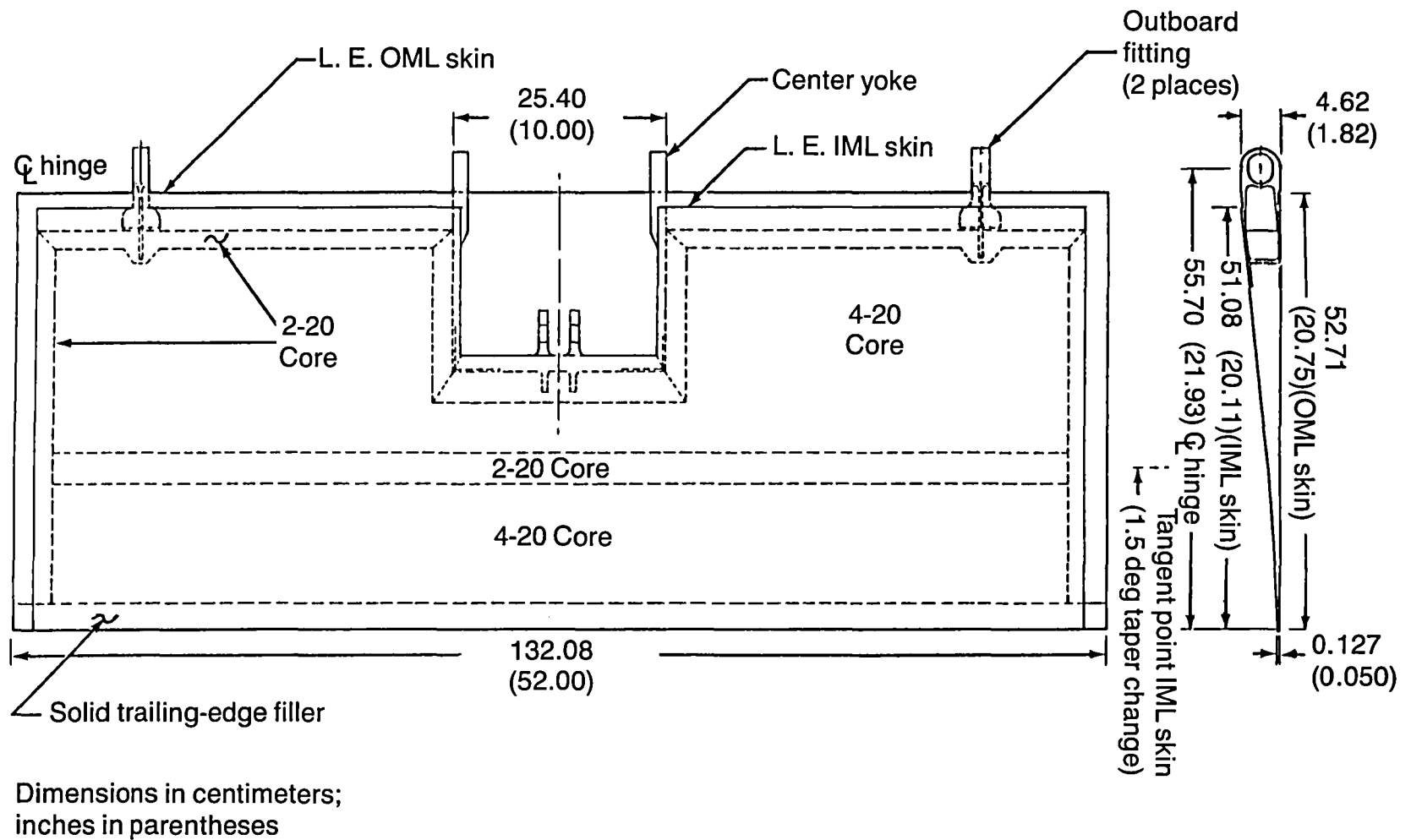


Figure 1. Preliminary Design Test Panel

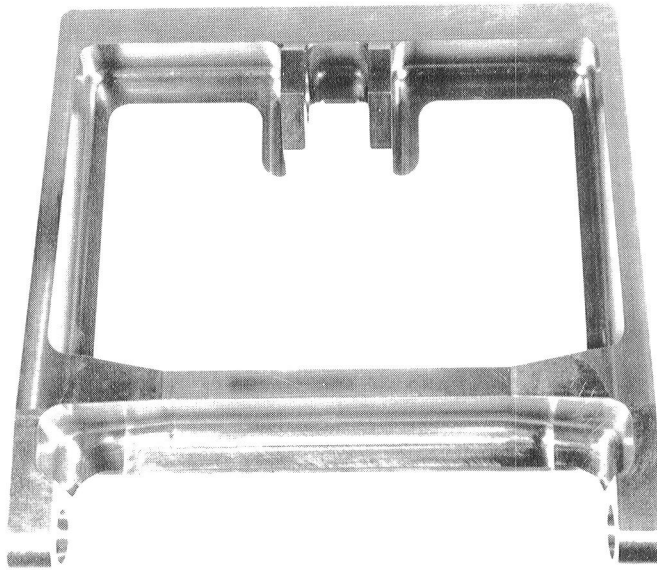


Figure 2. Flight Spoiler—Center Yoke Model

the tang, providing for a solid brazement and eliminating the possibility of tang markoff. The outboard hinge fitting configuration is illustrated in Figure 3. The faying-surface skin-to-fitting brazement was accomplished using spotweld gap control. The core was shear-tie brazed to the tang and nested between the flanges to accomplish the flange-to-core brazement. A detailed schematic of the spoiler layout is presented in Figure 4. An as-brazed flight configuration spoiler is shown in Figure 5.

Six electrical deflection indicators (EDIs), one rosette, and two axial strain gages were attached to the test spoiler to measure normal deflections and in-plane strain. Simulated air pressure was applied to the upper surface of the spoiler with eight rubber pads and an evenner linkage system by two hydraulic actuators, used to apply loads in both directions, as shown in Figure 6. The spoiler was statically loaded to 75% design limit load, fatigue tested for 300,000 cycles at a maximum cyclic load of 75% design limit load with $R = -0.2$, and statically loaded to design limit load. The spoiler loading was based on maximum actuator output. A maximum cyclic load of 75% design limit load with $R = -0.2$ was selected as a conservative operational load for test. The test data and stress analysis demonstrated compliance with the structural requirements of FAR 25. Accordingly, the FAA certified the spoilers for airline use.

No evidence of any problem was detected in the spoiler, visually or through the strain gages, during the fatigue testing. However, two cracks were detected in the upper skin after the load pads were removed for inspection. Failure analysis revealed that the fatigue cracks initiated at about 175,000 cycles. The loading pads were reinstalled and the spoiler was again statically loaded, this time to 100% design limit load; tip deflections were the same as for the original static loading (Fig. 7). A more detailed description of the testing is contained in reference 6.

The skin cracks that formed during the fatigue testing initiated at sharp corners at the aft end of the center yoke. These corners were rounded off for future design to reduce the stress concentration in this area, a change that was incorporated in spoiler S/N 003.

Three EDIs were mounted on each of the flight spoilers, S/N 002 and 003. The spoilers were loaded to design limit load and the deflections recorded. At the end of flight testing, each spoiler was retested in an identical manner. Comparison of spoiler deflections before and after the flight service evaluation provides an accurate assessment of any degradation in structural integrity during service.

Following static loading, the spoilers were prepared for flight service. The exposed core at the edge of the spoilers was given an Alodine 1200 treatment, and the remaining surfaces were abrasive blasted with 200-mesh aluminum oxide to prepare the surfaces for painting. The spoilers were coated with DeSoto 513-751 polyurethane primer and DeSoto 822-T-203 polyurethane enamel. The required edge and flap seals, rub strips, and bearings were installed. A spoiler completed to flight configuration is shown in Figure 8.

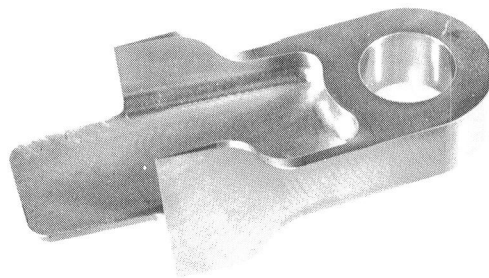
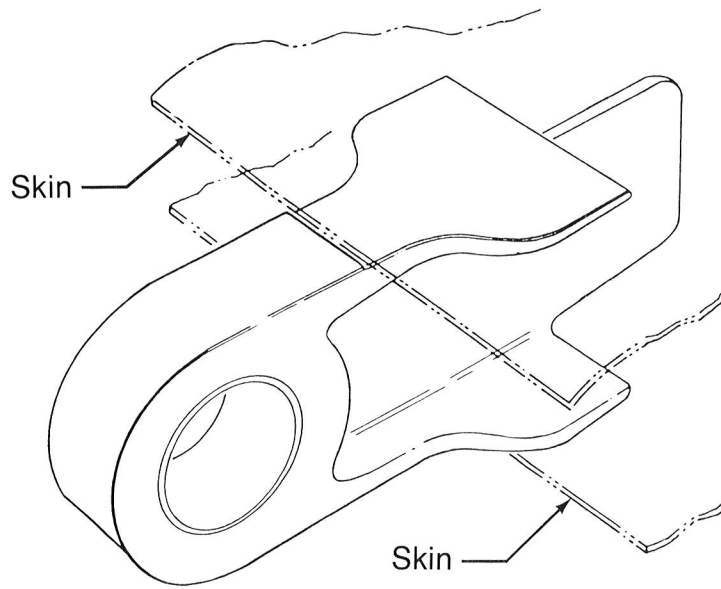
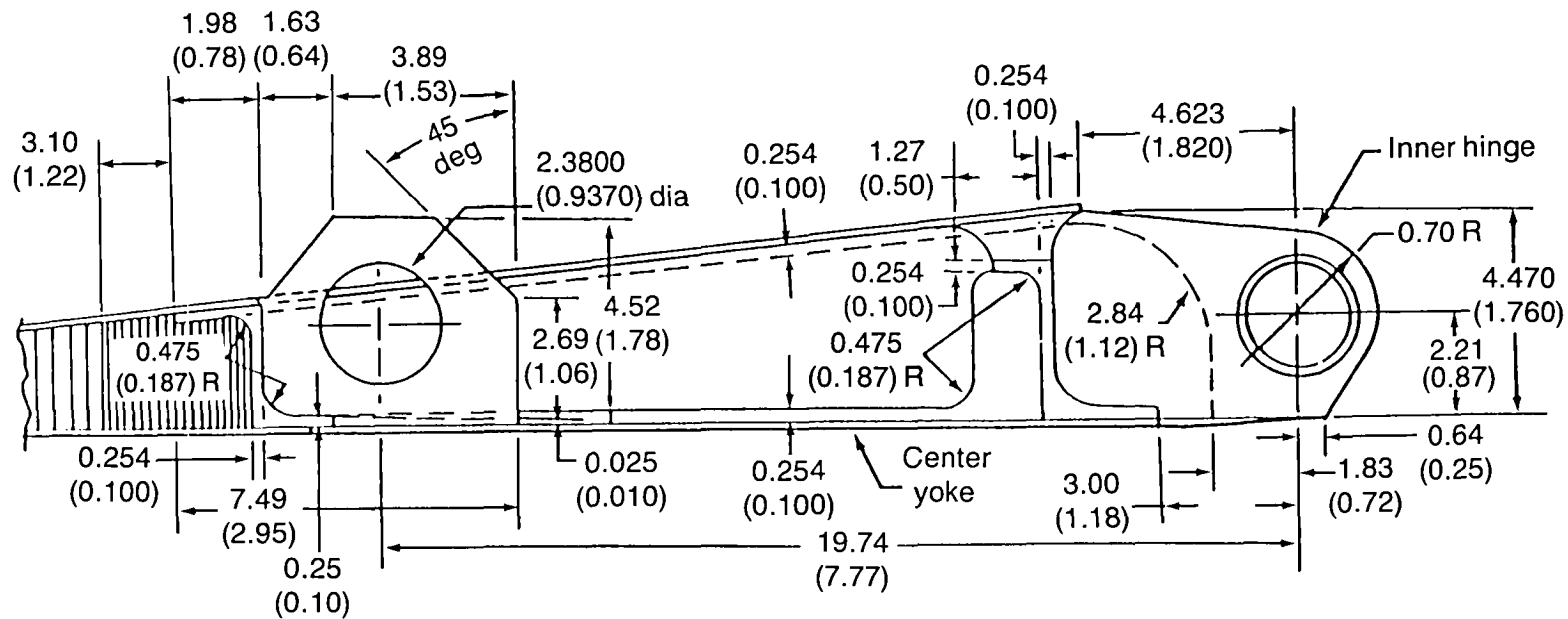


Figure 3. Flight Spoiler Outboard Fitting



View B-B

Dimensions in centimeters;
inches in parentheses

Figure 4. Flight Spoiler Schematic (Concluded)

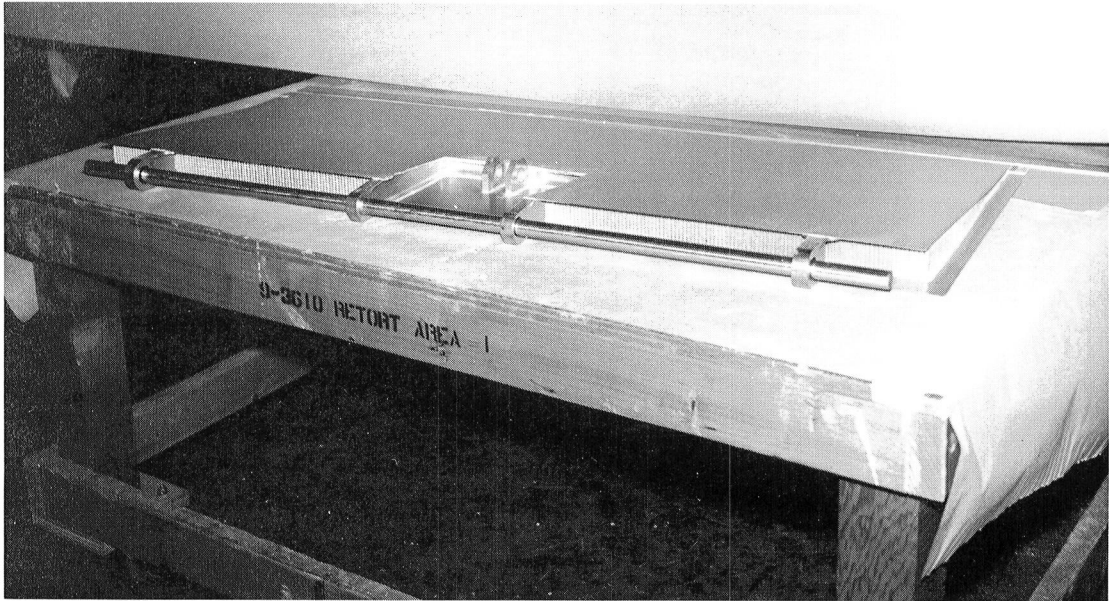
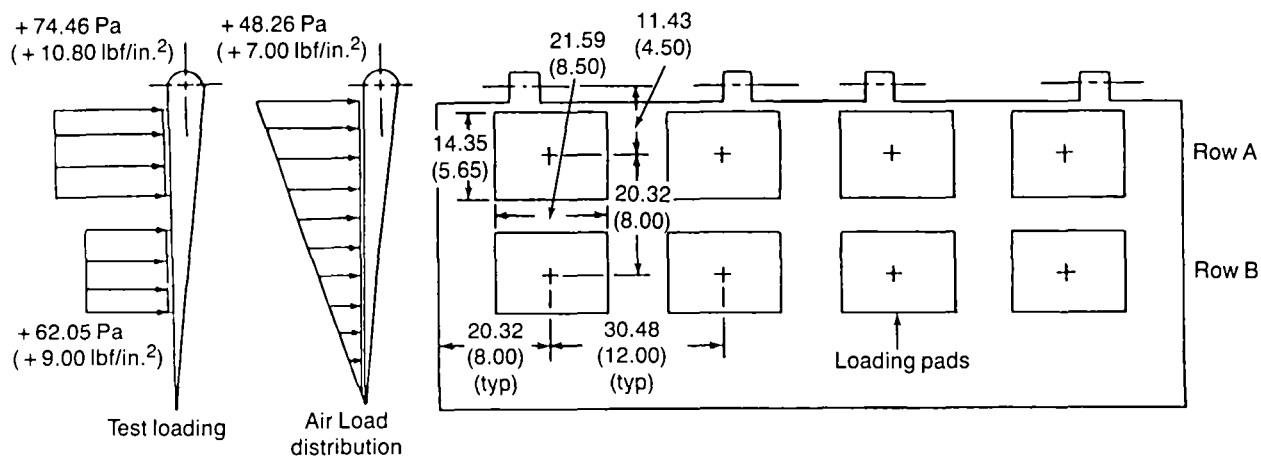


Figure 5. Brazed Flight Spoiler—S/N 002

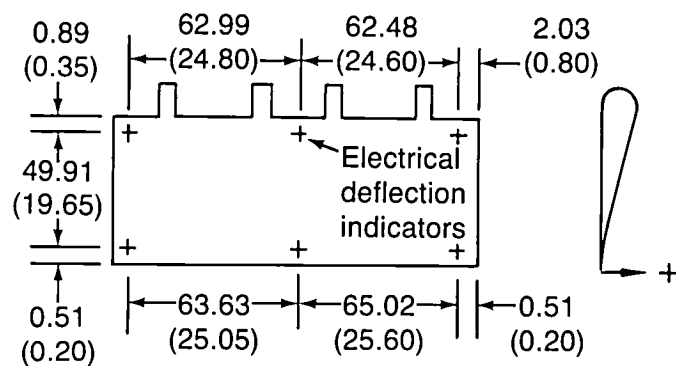


Dimensions in centimeters;
inches in parentheses

		Pad load, kg (lb)			
Pad		1	2	3	4
Row	A	+ 235 (+ 519)	+ 235 (+ 519)	+ 235 (+ 519)	+ 235 (+ 519)
	B	+ 195 (+ 429)	+ 195 (+ 429)	+ 195 (+ 429)	+ 195 (+ 429)

Total load + 1720 kg (+ 3792 lb) down

Figure 6. Flight Spoiler Design Limit Load



Dimensions in centimeters;
inches in parentheses

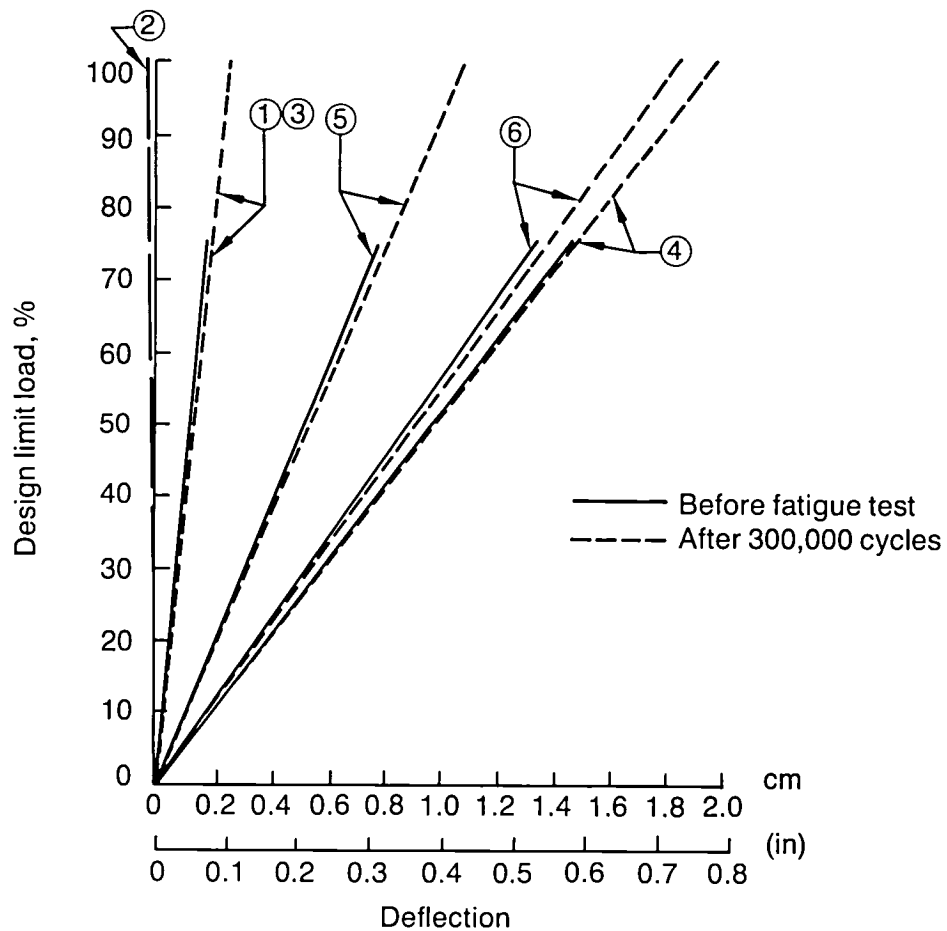
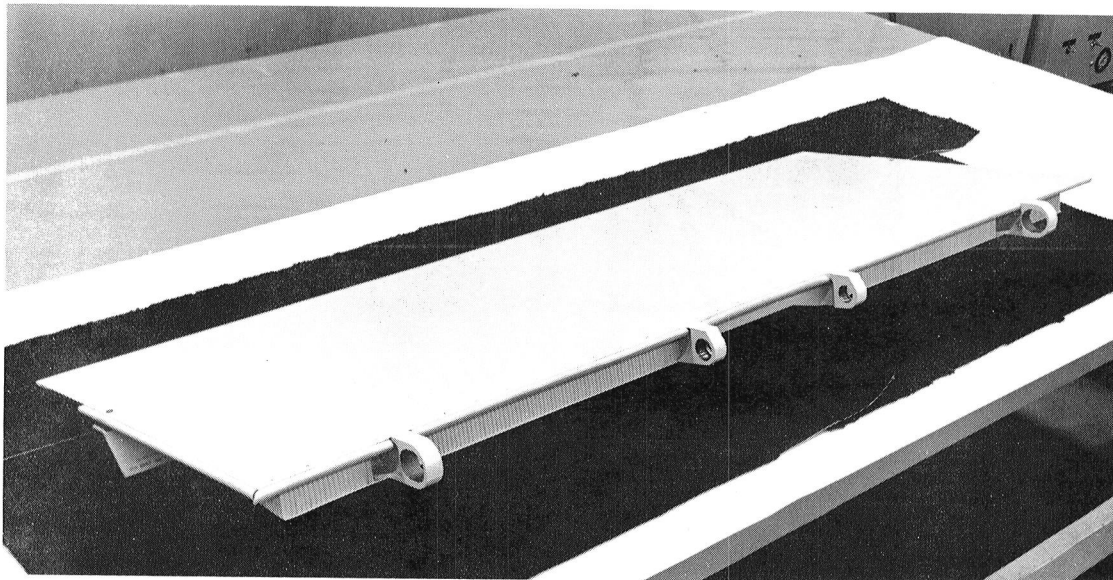
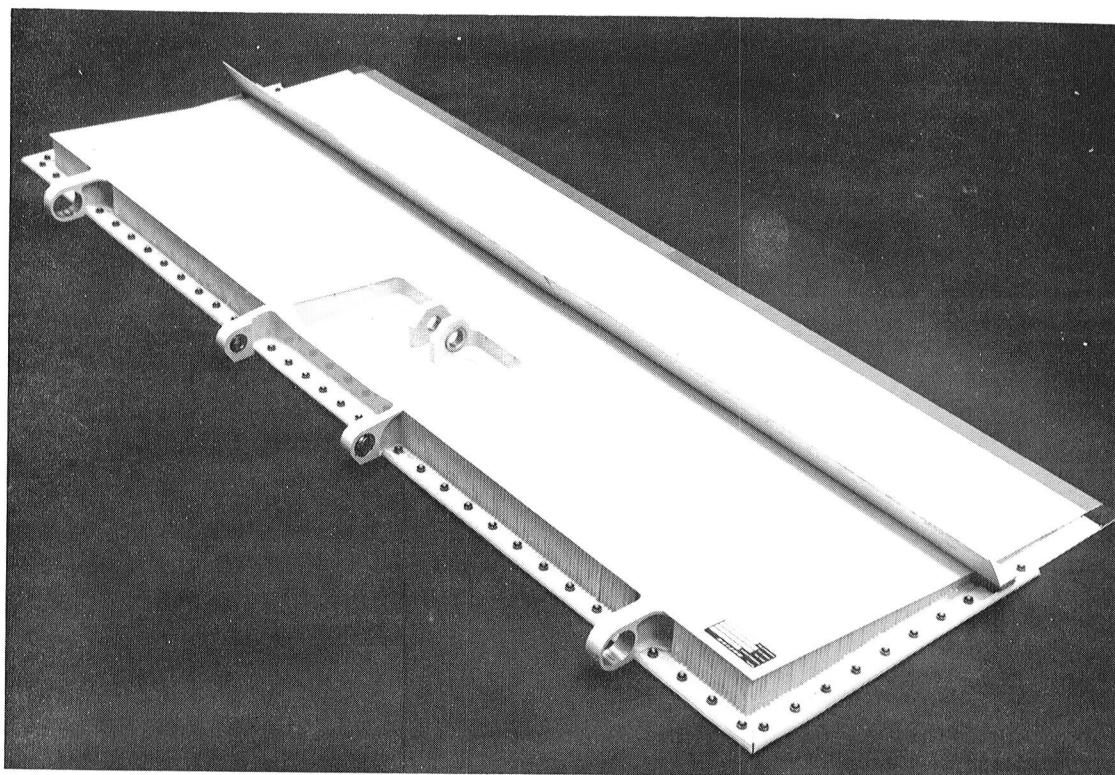


Figure 7. Flight Spoiler Deflection



(a) Upper surface



(b) Lower surface

Figure 8. Completed Flight Spoiler

4.0 FLIGHT SERVICE VALIDATION

The spoilers were mounted on All Nippon Airways Model 737 aircraft. The test plan was to provide a service evaluation under routine airline operating conditions. All Nippon Airways was selected because its routes provide the severe corrosion conditions encountered in a marine-industrial environment. The spoilers form a part of the upper exterior surface of the airplane wing and are directly exposed to the spray, runway deicing materials, and engine exhaust deposits resulting from use of the thrust reversers.

The spoilers were flown on three different aircraft. Since they were removed and reinstalled at different times, the two spoilers had slightly different numbers of flight hours and flight cycles. Spoiler S/N 002 was initially installed on April 2, 1974 and spoiler S/N 003 on September 9, 1974. Spoiler S/N 002 was always deployed at the inboard position of the right wing and spoiler S/N 003 at the outboard position of the left wing (Fig. 9). The total service experience for the two spoilers is indicated below:

Spoiler S/N	Flight Hours	Landings
002	16,731	17,325
003	15,684	16,268

This experience was accumulated over a span of about 8 years; the spoilers were removed from service on November 12, 1982.



Figure 9. Location of Flight Spoilers on All Nippon Airways Model 737

4.1 ON-SITE INSPECTIONS

On-site inspections were conducted at the All Nippon Airways flight hangar or maintenance center in Osaka, Japan. Inspections were scheduled in conjunction with aircraft maintenance checks and included visual, coin-tap, and eddy-current testing. No discrepancies or problem areas were detected through these inspections. Key comments from the inspections are summarized below.

July 1975

- The spoilers were in excellent condition, with no sign of wear or degradation.
- The aerodynamic seal flaps were not being used by All Nippon Airways. They were removed by drilling out the blind rivets, potting in the holes, and taping over the entire region. (The tape requires periodic replacement.)
- There was no indication of corrosion or loss of braze integrity by eddy-current or coin-tap inspection.

March 1976

- There was no spoiler degradation beyond normal wear on rubbing surfaces and minor paint damage.
- There was some paint wrinkling on the leading-edge core due to Skydrol attack. This is considered normal.
- Ultrasonic C-scans were performed. The results are discussed in Section 4.2.

(This inspection was accomplished in Seattle, as discussed in Section 4.2.)

December 1977

- Visual and eddy-current inspections indicated no changes from the original as-fabricated condition, except for slight disbonding of the adhesive-bonded doublers. The doublers were installed to provide a fastening base for the aerodynamic seal. The disbonding occurred on the trailing edge of both spoilers on both the inboard and outboard sides. It extended about 6.35 mm (0.25 in.) on spoiler S/N 002 and 19.1 mm (0.75 in.) on spoiler S/N 003. The disbonding was attributed to excessive flexure during installation. Although the disbonds were nonstructural, it was recommended that All Nippon Airways repair them with Monel rivets.
- The paint condition was the same as reported in 1976.

November 1978

- Visual and eddy-current inspections again showed no changes from the as-brazed condition, except in the doubler area. The extent of disbonding remained unchanged, except that the

disbond on the inboard side of the spoiler S/N 003 doubler was now 7.6 cm (3 in.) long. The separation tip now approached the first seal fastener location, which will prevent further growth.

- The paint condition was the same as reported in 1976.

December 1979

- Visual and tap-test inspections showed no change from the original condition.
- A small dent was noted in the honeycomb core at the forward outboard corner of spoiler S/N 002.
- There was additional paint wrinkling on the leading-edge core of both spoilers due to Skydrol. Three edge-seal fastener heads on spoiler S/N 002 showed loss of paint and some evidence of corrosion.
- The doubler disbond condition was the same as reported in 1978, except that the disbonded portion of the doubler on the inboard side of spoiler S/N 003 was removed.

January 1981

- Visual and tap-test inspections showed no change from the original condition.
- There was no evidence of a corrosion problem. Evidence of corrosion on the edge-seal fastener heads was still present.
- Disbonded areas of the doubler on spoiler S/N 003 were repaired with universal-head MS aluminum alloy rivets.

November 1981

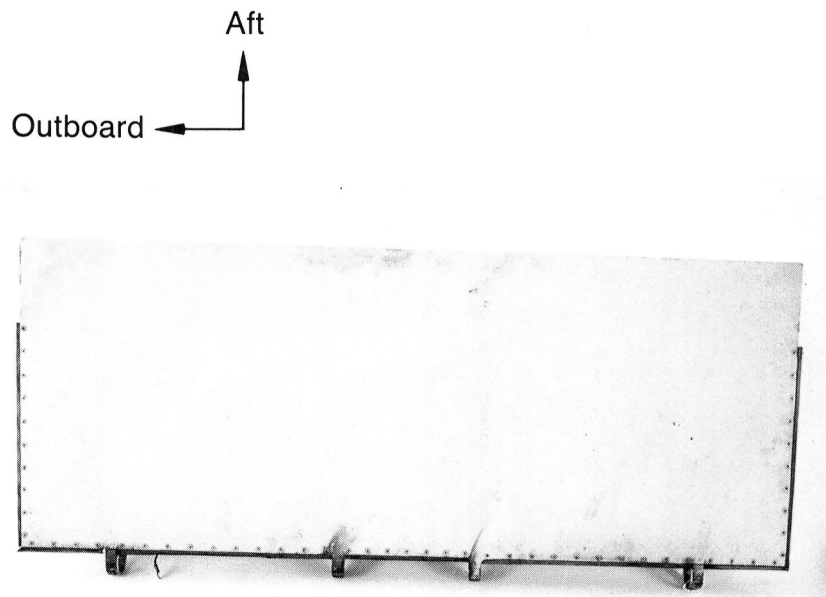
- Visual and tap-test inspections showed no change from the original condition.
- Two small dents were observed near the outboard trailing edge of spoiler S/N 002. There was no evidence of delamination or structural damage due to the dents.
- Several edge-seal fasteners had lost paint on the heads and corrosion was noted.

April 1983

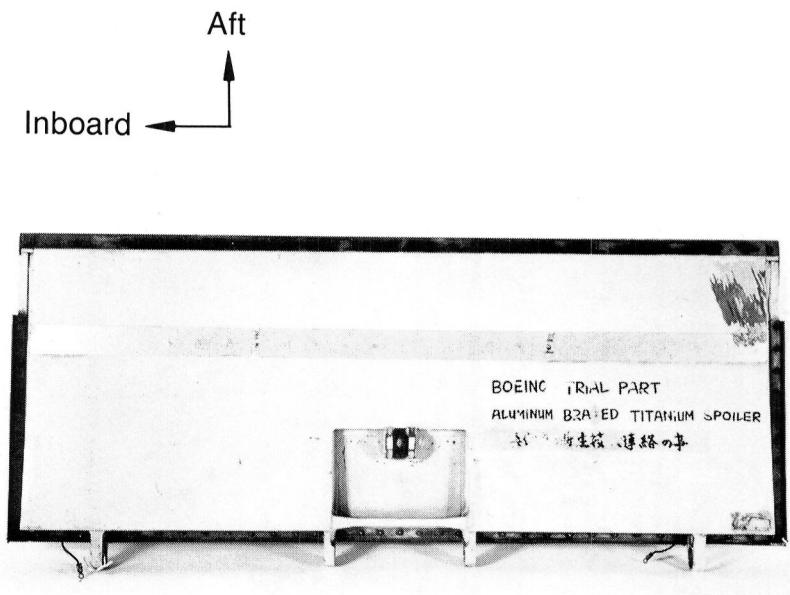
- The spoilers were removed and inspected at Boeing in Seattle.
- Structurally, the spoilers appeared to be in excellent condition.
- There was evidence of paint loss on both spoilers due to rubbing or abrasion, as shown in Figures 10 and 11. The paint on the exposed surface of the center yoke fitting (lower surface) was extensively blistered due to Skydrol (Fig. 12). There was some blistering on the lower

skin surface adjacent to the yoke. This was more prevalent on spoiler S/N 002 on the outboard portion of the skin. The worst paint problem occurred on the leading-edge core (Fig. 13). None of this blistering or actual peeling of paint, particularly on the core, led to any corrosion.

- Some damage to the exterior core had occurred. A core node right at the leading edge outboard corner almost appeared to have been cut on spoiler S/N 002 (Fig. 14). The extent of the opening was about 1.3 cm (0.5 in.). (Damage was reported in this area in the 1979 on-site inspection.) Spoiler S/N 003 had damage to both the inboard and outboard edges. It appeared to have been hit and torn apart on the lower surface. On the outboard surface, there was a disbond across three cells—1.9 cm (0.75 in.)—about 1.5 cm (0.6 in.) aft of the leading edge (Fig. 15). On the inboard surface, there were three damage regions (Fig. 16). One cell, about 4.1 cm (1.6 in.) aft of the leading edge, appeared to have been struck by a sharp object. The second and third cells aft of the leading edge also appeared to have been torn loose on the lower surface. The corner node apparently was struck by a dull object and torn open. There was no evidence of corrosion at any of these sites.
- The repaired doublers on spoiler S/N 003 were delaminated forward to the repair fasteners. The doublers on spoiler S/N 002, which were not riveted, were delaminated about 2.3 cm (0.9 in.) on the inboard side and 2.5 cm (1 in.) on the outboard side (Fig. 17).
- The corrosion on the heads of the edge-seal fasteners was minor.

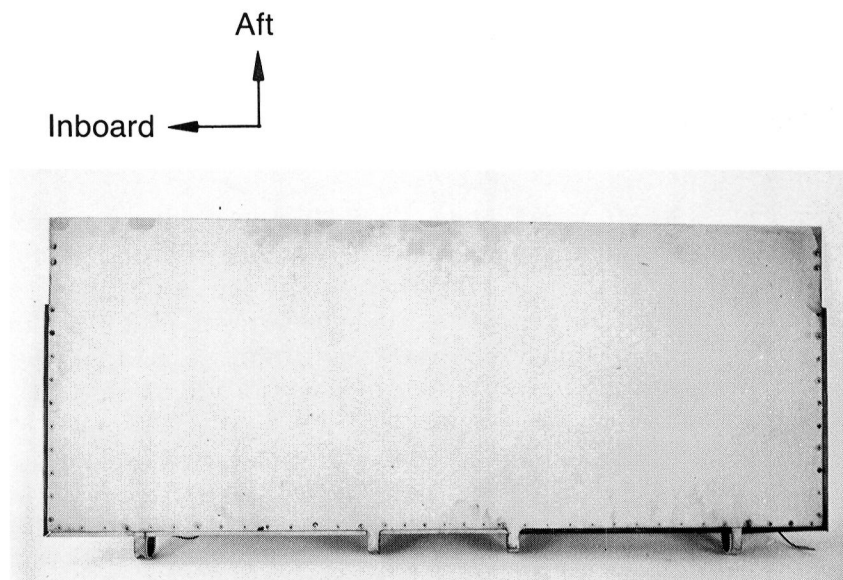


(a) Upper surface

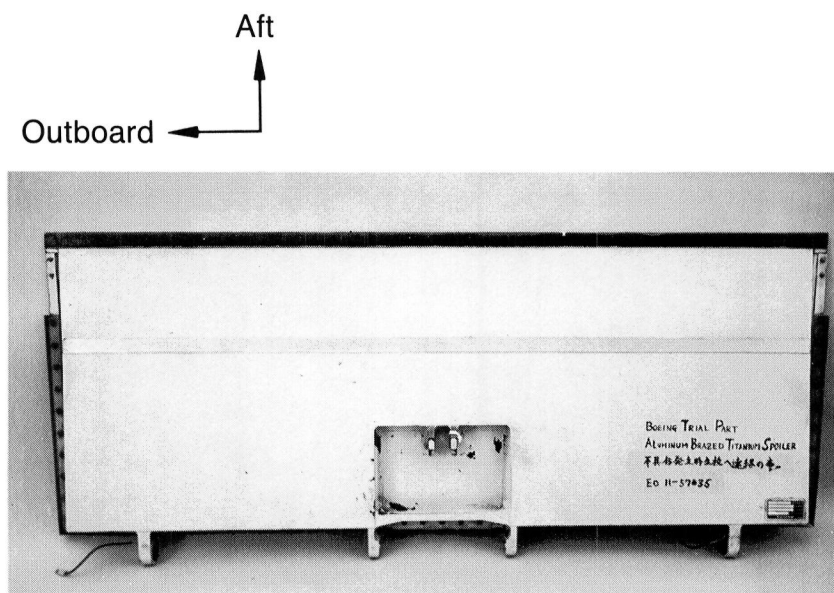


(b) Lower surface

Figure 10. Flight Spoiler S/N 002 After About Eight Years of Service



(a) Upper surface



(b) Lower surface

Figure 11. Flight Spoiler S/N 003 After About Eight Years of Service

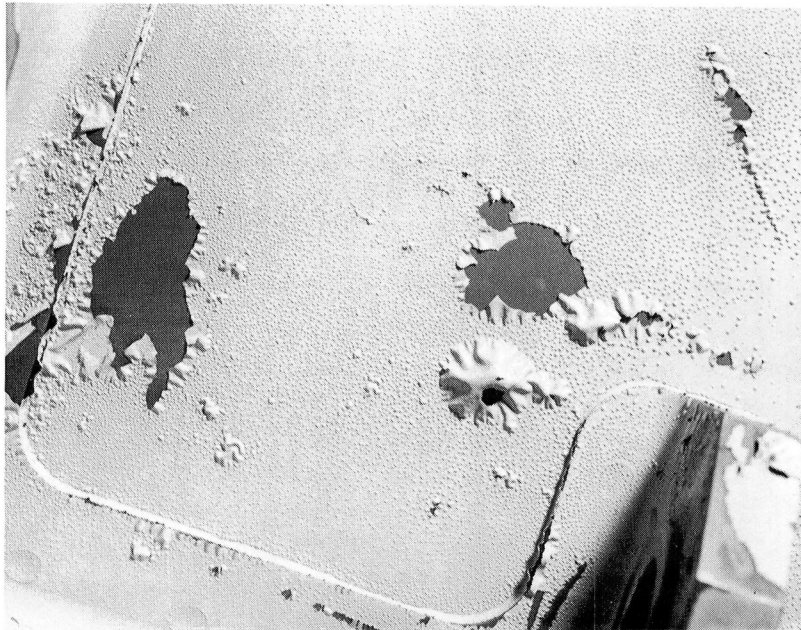


Figure 12. Paint Blistering and Peeling Due to Skydrol on Center Yoke Fitting, Spoiler S/N 002

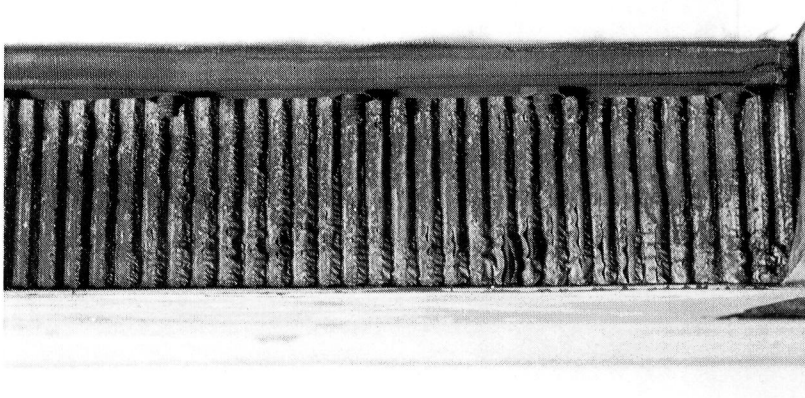


Figure 13. Paint Blistering and Peeling Due to Skydrol, Typical of Leading-Edge Core

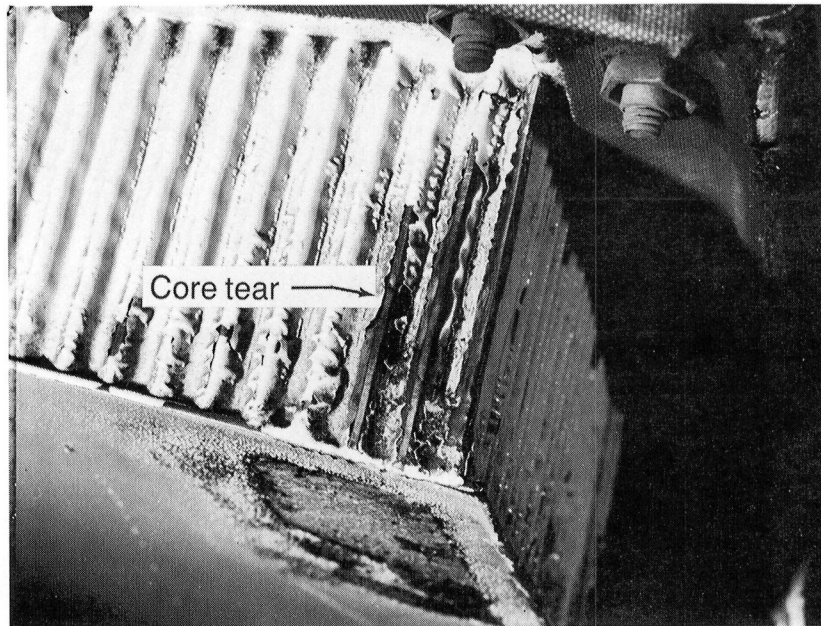


Figure 14. Damaged Core Observed at Leading Edge, Outboard Core, Spoiler S/N 002

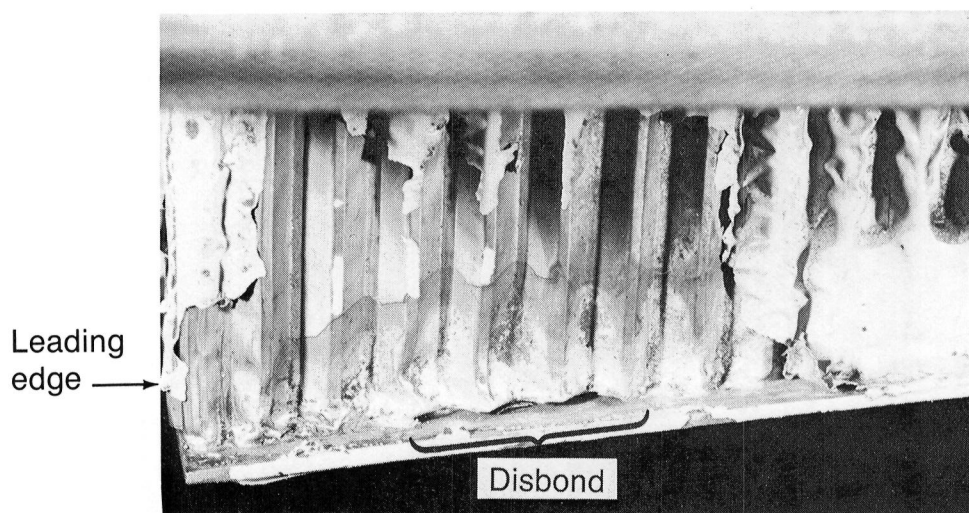
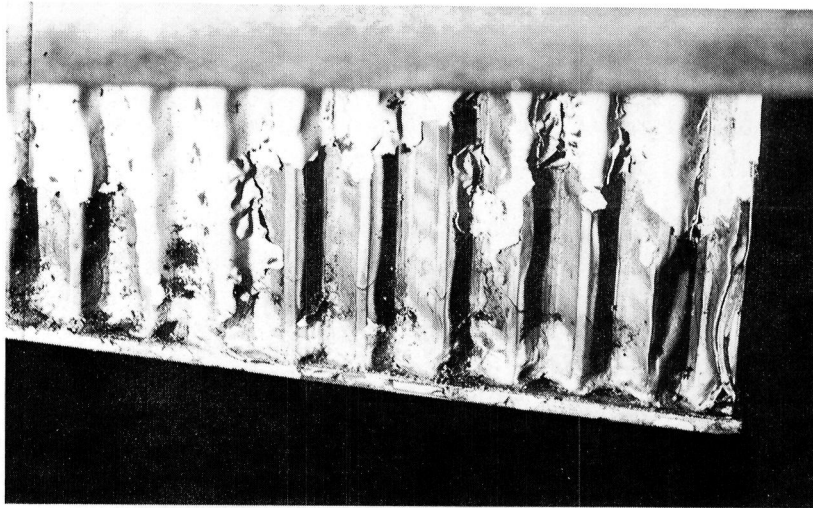
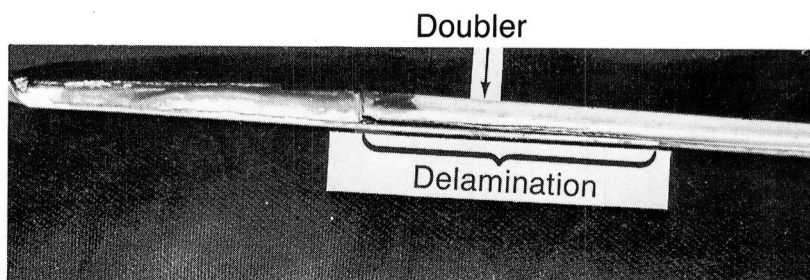


Figure 15. Disbond on Lower Surface, Outboard Edge, Spoiler S/N 003



Note hole at corner node, obviously hit by a dull object. Second and third cells aft are disbonded, and there is an apparent puncture five cells farther aft.

Figure 16. Damaged Areas Near Leading Edge at Inboard Lower Surface, Spoiler S/N 003



Extent of delamination about 2.3 cm (0.9 in.)

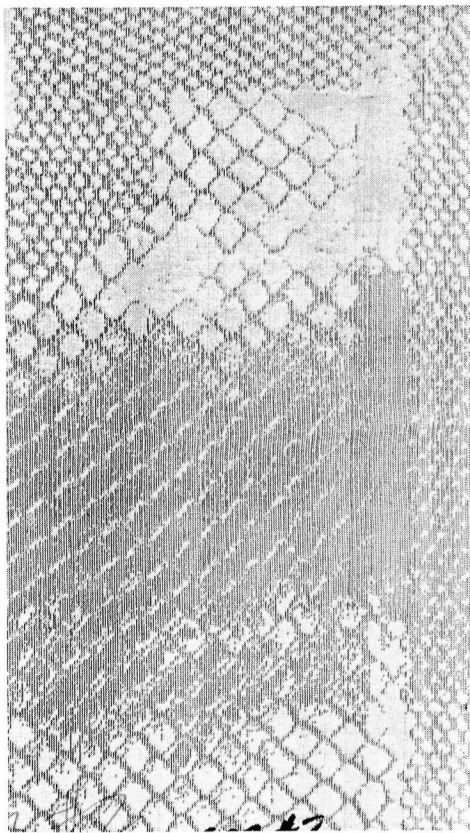
Figure 17. Doubler Delamination on Inboard Side, Spoiler S/N 002

4.2 ULTRASONIC C-SCAN INSPECTIONS

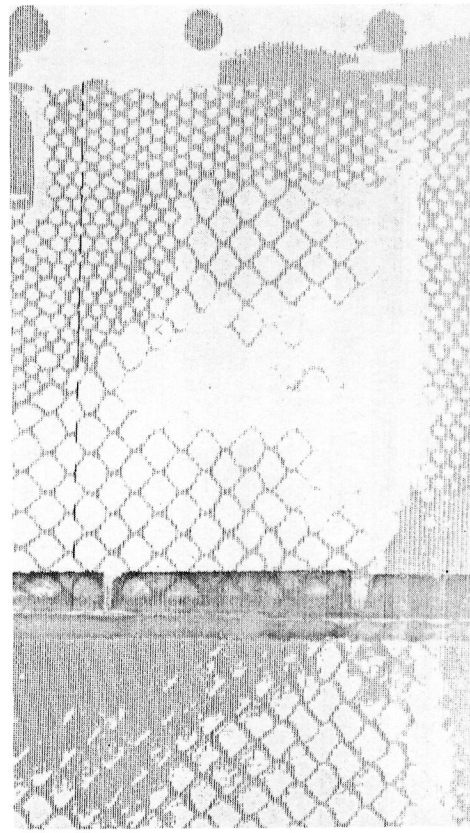
Both spoilers were inspected by pulse-echo ultrasonic C-scan after braze fabrication, before delivery to All Nippon Airways, in 1973. It was necessary to renegotiate the service contract in March 1976. The spoilers were shipped back to Boeing and ultrasonic inspected at that time. They were reinstalled in late 1976 and saw continuous service through late 1982, the end of the service contract. The spoilers were shipped back to Boeing and ultrasonic inspected a final time.

The initial inspection revealed two void areas. Spoiler S/N 002 had a fairly large void at the inboard edge of the SC 4-20 core, adjacent to the peripheral high-density core, near the leading edge. Figure 18 presents the 1973, 1976, and 1983 C-scans of the upper surface. The void was about 15.9 cm (6.25 in.) long and about 6.4 cm (2.5 in.) deep at its widest point. The void was not quite as long on the lower surface; it extended aft about 8.9 cm (3.5 in.) and was about the same maximum depth, 6.4 cm (2.5 in.) (Fig. 19). (The 1973 C-scan for the lower surface was misplaced.) The data from these ultrasonic C-scans are very encouraging. It is difficult to precisely trace the shape of the void through the years due to differences in quality of the C-scans, but the void does not appear to have grown through the approximately 8 years of service.

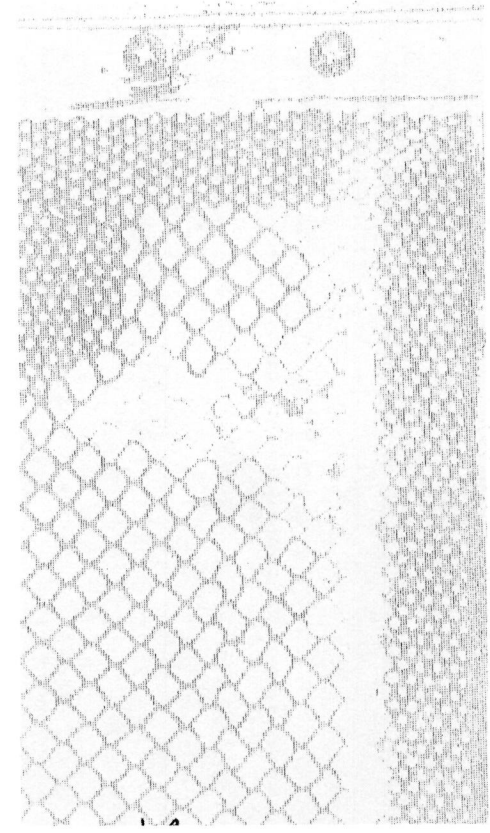
The void area was excised from the spoiler for analysis. The excised specimen was cut in half through the core (and the core ground down to a minimal core height to facilitate examination), so that the brazes on the upper and lower surfaces could be studied. The total absence of any corrosion product made it apparent that no corrosion had occurred. The void was present from the date of manufacture and was due to double cell walls that contained contaminant (Fig. 20). The correlation between ultrasonic inspection and the size of the actual void was excellent, as can be seen by comparing Figures 18 and 20.



(a) 1973



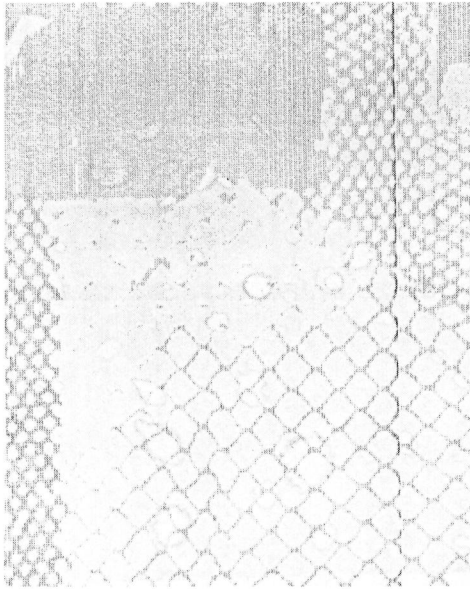
(b) 1976



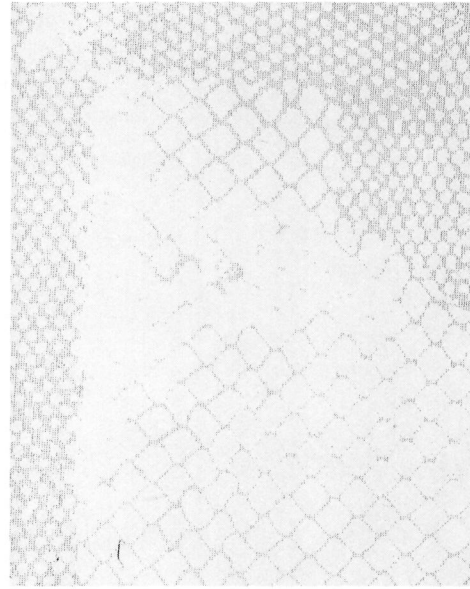
(c) 1983

Reduced to 65% of actual size

Figure 18. Pulse-Echo Ultrasonic C-Scans of Spoiler S/N 002, Upper Surface, Showing Braze Defect in Area of Inboard Leading Edge as a Function of Time



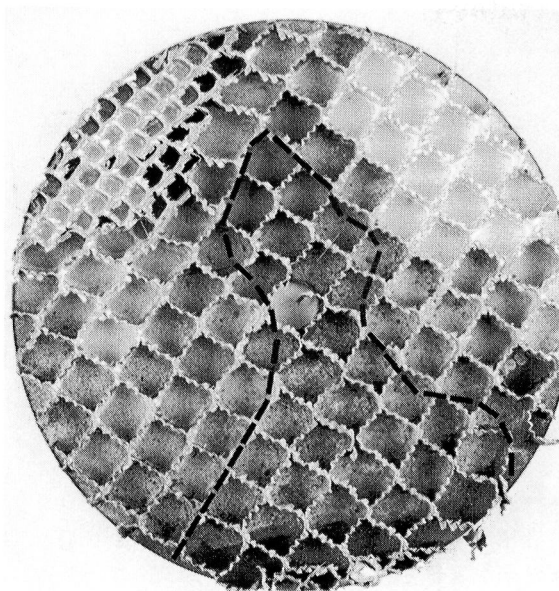
(a) 1976



(b) 1983

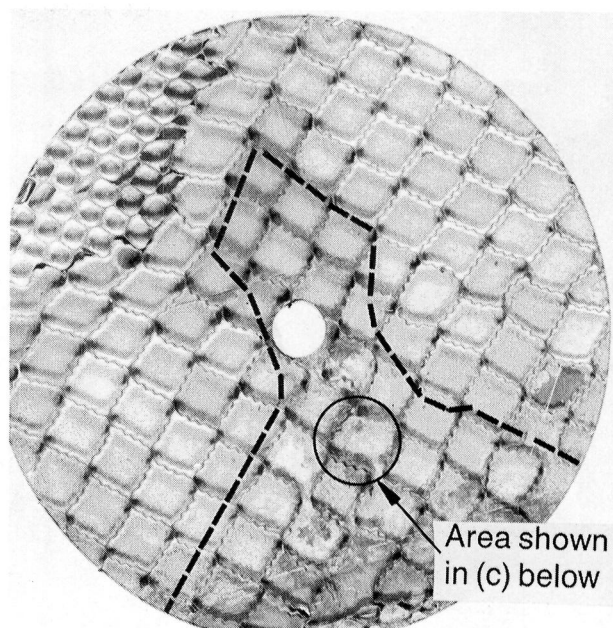
Reduced to 65% of actual size

Figure 19. Pulse-Echo Ultrasonic C-Scans of Spoiler S/N 002, Lower Surface, Showing Braze Defect in Area of Inboard Leading Edge as a Function of Time



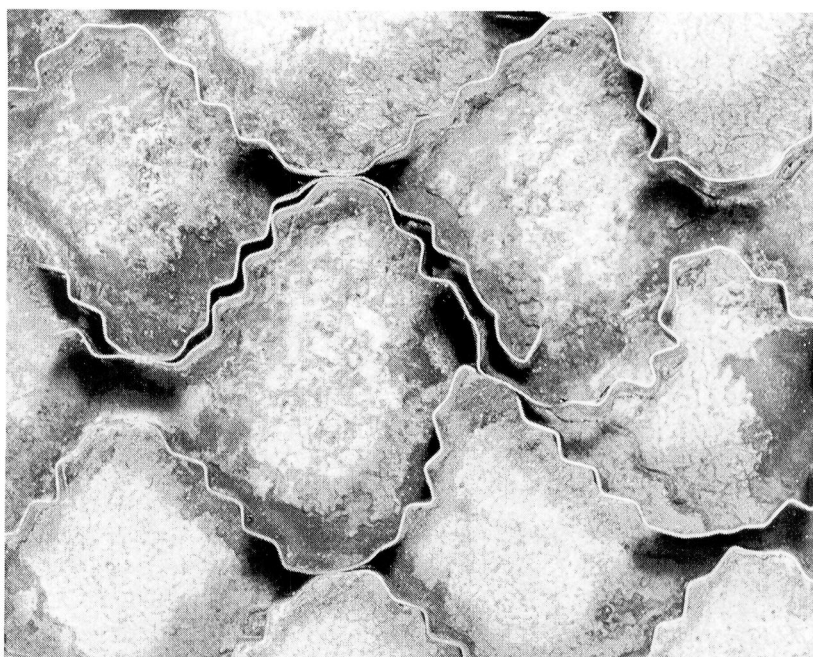
1X

(a) Dark zone due to contamination from double cell walls illustrated in (b) and (c)



1.1X

(b) Periphery of no-braze area



4.5X

(c) Double cell walls

Figure 20. Section of Void Detected by Ultrasonic Inspection of Spoiler S/N 002, Upper Surface (Corresponds to C-Scan of Figure 18)

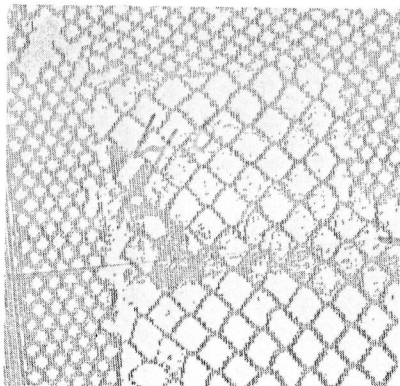
Another, smaller void was observed in the SS 2-20 core in the lower surface of spoiler S/N 003 near the outboard leading edge (Fig. 21). Its maximum dimensions were about 1.3 and 1.7 cm (0.5 and 0.65 in.). The size of this defect could not be determined in 1976, because the part label blocked the scan. This void was considerably larger in 1983, however, as can be seen in Figure 21. It appeared to have extended to the surface and grown to the interior edge of the SS 2-20 core. The disbond on the edge indicated by the C-scan appeared to be more extensive than the three separated cells observed visually.

This void also apparently was present from the date of manufacture. The extent of this defect is delineated in Figure 22 by the darkened zone. There are four reasons that it is felt this defect existed from the date of manufacture:

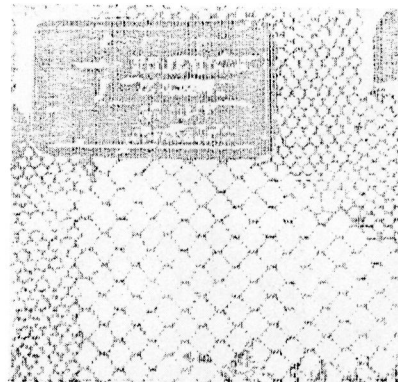
1. The core in the void area was crushed, resulting in a core standoff of 0.5 mm (0.020 in.) or more. This amount of standoff would be sufficient to prevent bridging of the braze alloy between the face sheet and core, so that no braze could occur. This is illustrated in Figures 23 and 24. Figure 23a demonstrates the core distortion and Figure 23b shows the general extent of the standoff by the presence of shadows. Figure 24 presents a metallurgical cross section illustrating the shape of the core in the crushed-core region. The braze shown in Figure 24 was at the edge of the void; the crushing was not quite as extensive and brazing did occur.
2. There were only minor amounts of corrosion product in scattered cells. If the defect grew by corrosion, one would expect a copious amount of corrosion product. This was not observed.
3. Aluminum braze alloy was still present on the face sheet (Fig. 25). If the void grew by a corrosion mechanism, the thin layer of braze alloy present on the face sheet would be gone.
4. Metallurgical cross sections of the outer periphery of the void showed no evidence of mechanical damage to the existing braze fillets—there simply were no fillets in the void region. This indicates that the void could not have enlarged due to mechanical loads.

Based on the above observations, no explicable means of void growth can be found to account for the difference in void size between 1973 and 1983. The standoff between the core and face sheet appeared sufficient to prevent forming a brazement. Thus, the apparent growth of the void as indicated by the ultrasonic C-scans is attributed to nuances in the ultrasonic inspection process. The more accurate definition of the defect in 1983 may be due to improvements in ultrasonic equipment and technology over the 10-year period or perhaps to a better setup in that location of the spoiler.

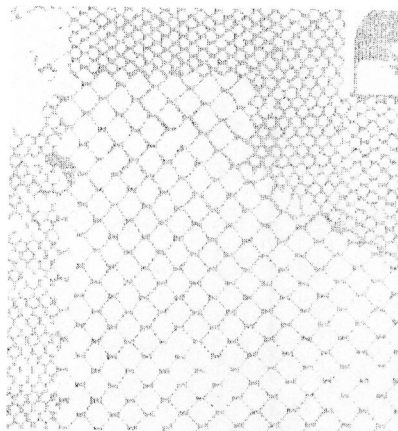
Four voids were detected on the inboard side of the lower surface of S/N 003, as shown in Figure 26. There was no visible evidence of defect A extending to the surface—it was totally internal (Fig. 27). The outer cells of defect A were filled with potting compound, as can be seen in Figure 27a. This would cause an impedance mismatch that could cause a strong echo and produce a void-like appearance. Taking this into account for defect A in Figures 26 and 27, the actual defects again correlated very well with those detected by the C-scan (Fig. 26). Defect B was three cells wide at the surface and corresponded to the external void apparent in Figure 15. All of the voids in this area (A, B, C, and D in Fig. 26) were due to a manufacturing defect, core crushing, which caused a standoff of about 0.5 mm (0.020 in.) that was not bridged by braze alloy. This core-face sheet standoff is illustrated in Figure 27b. The internal surface was bright and shiny, with no evidence of corrosion at any location.



(a) 1973



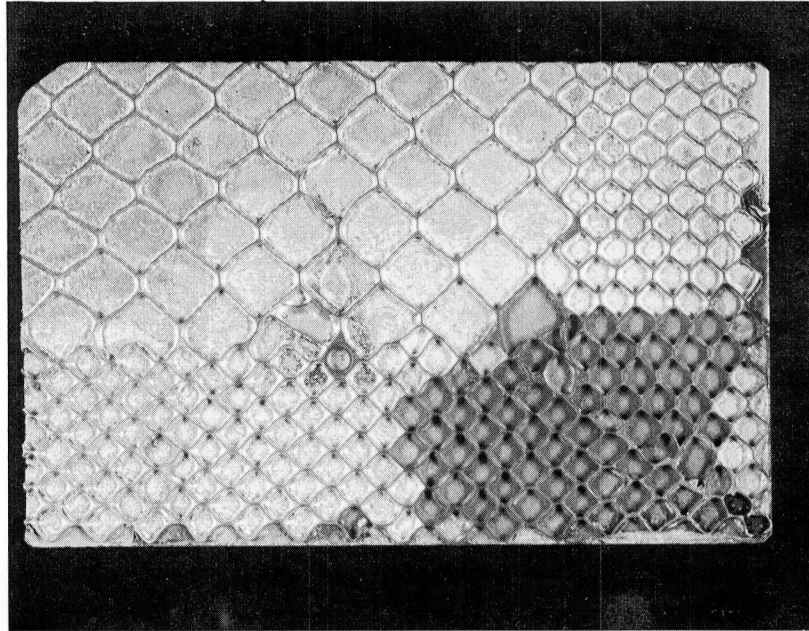
(b) 1976



(c) 1983

Reduced to 65% of actual size

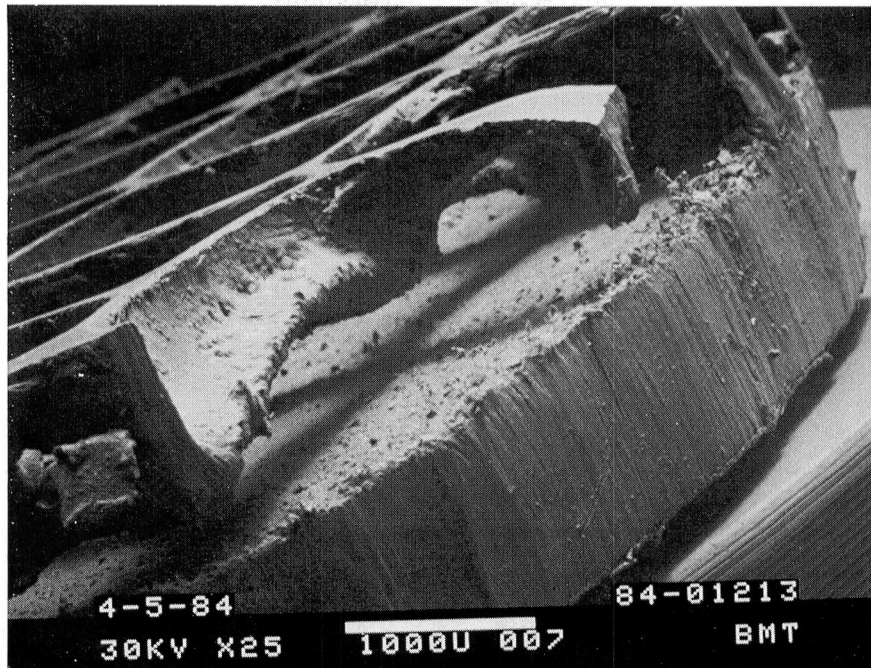
Figure 21. Pulse-Echo Ultrasonic C-Scans of Spoiler S/N 003, Lower Surface, Showing Braze Defect in Area of Outboard Leading Edge as a Function of Time



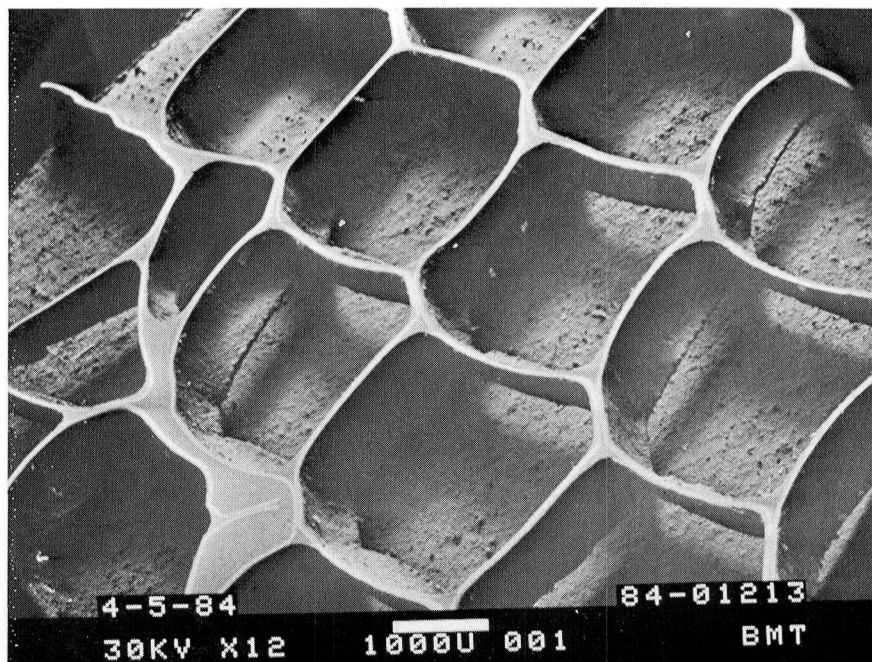
1.3X

Void corresponds to that observed in figure 21 C-scan

Figure 22. Photomacrograph of Void on Lower Surface Near Outboard Leading Edge, Spoiler S/N 003

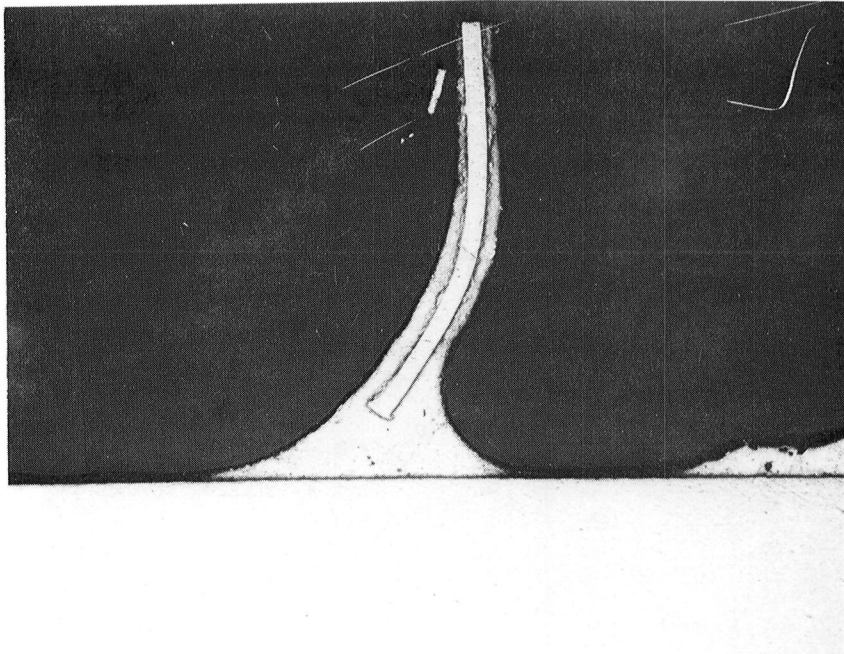


(a) Core distortion that occurred apparently during spoiler fabrication



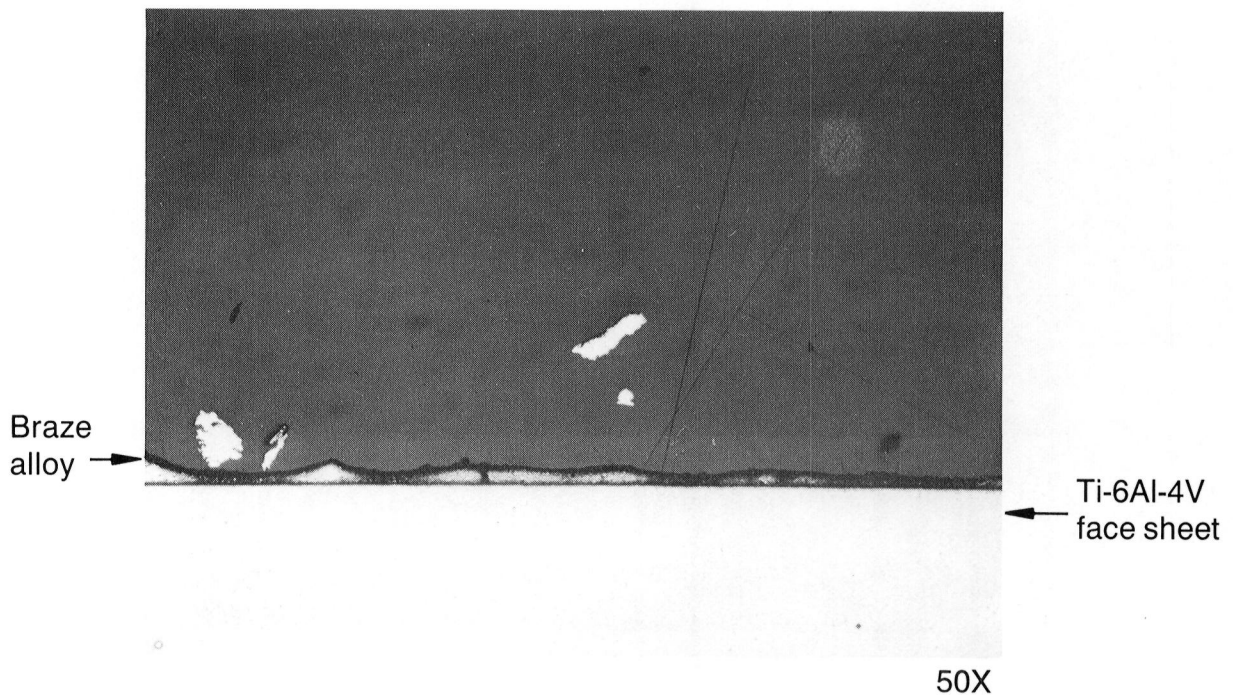
(b) Standoff (shown by shadows)

Figure 23. Backscattered Scanning Electron Micrographs Illustrating Crushed Core That Prevented Braze Occurrence on Lower Surface of Spoiler S/N 003 Near Outboard Leading Edge (Void from Figure 22)



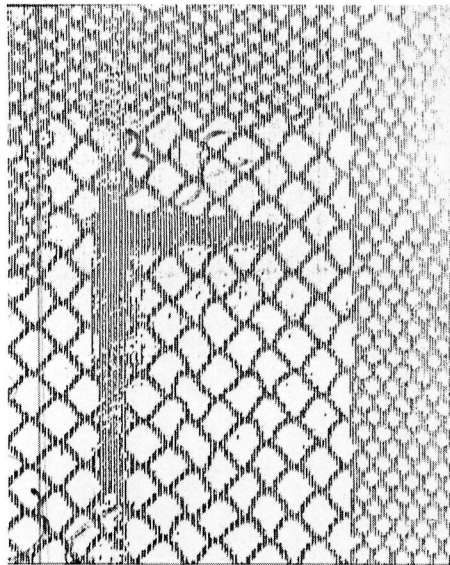
50X

Figure 24. Cross Section at Periphery of Crushed-Core Region Illustrating Cell-Wall Distortion

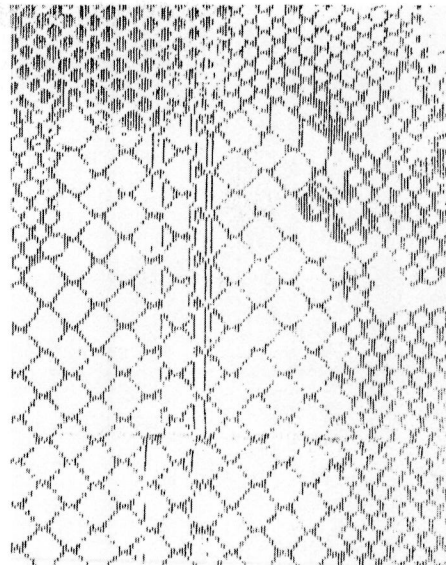


50X

Figure 25. Metallurgical Cross Section Through Center of Void Shown in Figure 22, Illustrating Remnant Braze Alloy on Face Sheet

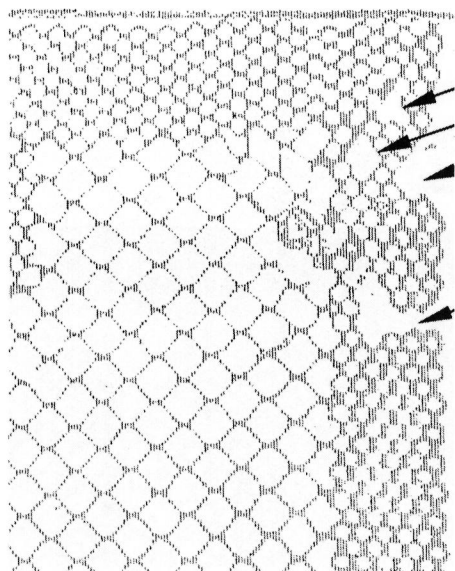


(a) 1973



(b) 1976

← Defect A



(c) 1983

Defect D

Defect C

Defect B

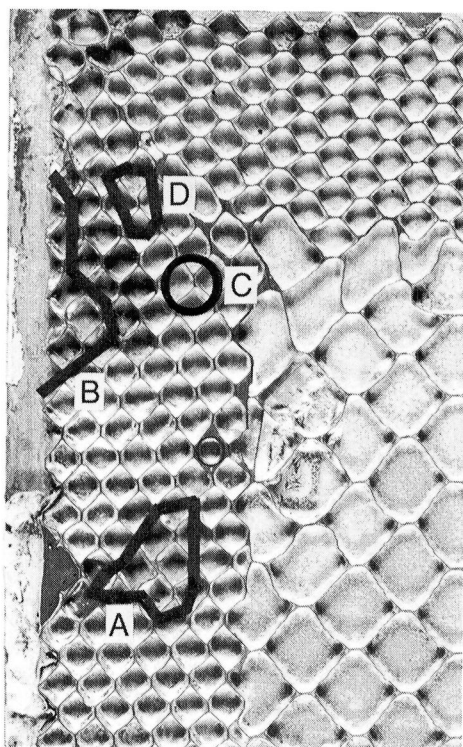
Defect A

Defect A detected in 1976

Defect B detected in 1983

Reduced to 74% of actual size

Figure 26. Pulse-Echo Ultrasonic C-Scans of Spoiler S/N 003, Lower Surface, Showing Braze Defects in Area of Inboard Leading Edge as a Function of Time



1.2X

(a) Void peripheries



1.4X

(b) Cell-wall standoff

Note: Solid lines in (a) indicate the extent of the voids; letters correlate to figure 26. The cell-wall standoff is apparent by the shadows in (b).

Figure 27. Defects on Lower Surface of Spoiler S/N 003 in Area of Inboard Leading Edge

4.3 STRUCTURAL LOAD TESTS

The final, and possibly most significant, means of verifying the structural durability of the spoilers was by comparing spoiler deflections upon imposition of design limit load before and after flight service. The spoilers were mounted to a strongback at the hinge points. Simulated air pressure was applied to the upper surface of the spoiler with eight rubber pads and an evener linkage system by two hydraulic actuators used to apply loads in both directions. The test setup used, shown in Figure 28, was the same as that used in the initial testing. The design limit load distribution of the spoilers was illustrated in Figure 6. The locations of the load pads and the three EDIs are shown in Figure 29. The load and EDI readings were recorded at 15% increments through 90% design limit load, then at 100% design limit load, 1720 kg (3792 lb). This was done twice for each spoiler. Neither spoiler took on a permanent set as a result of these tests.

The results are presented in Figures 30 and 31. For both spoilers, the deflections after flight service were less than for the as-fabricated condition, except for location 1 in each case. The preflight and postflight service data for EDI number 1 are probably within experimental error. Both spoilers appeared to be significantly stiffer in location 3, particularly spoiler S/N 002. The only plausible explanation for this is minor differences in load-pad or strain-gage positioning.

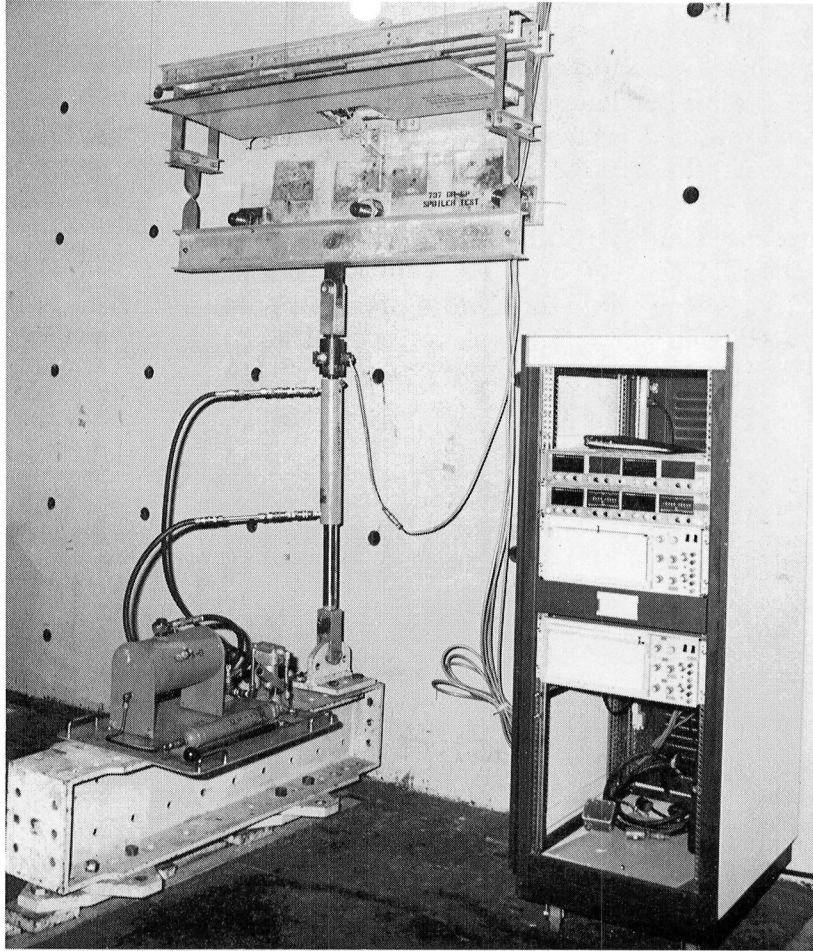


Figure 28. Test Setup for Applying Simulated Design Limits Loads to Flight Spoilers

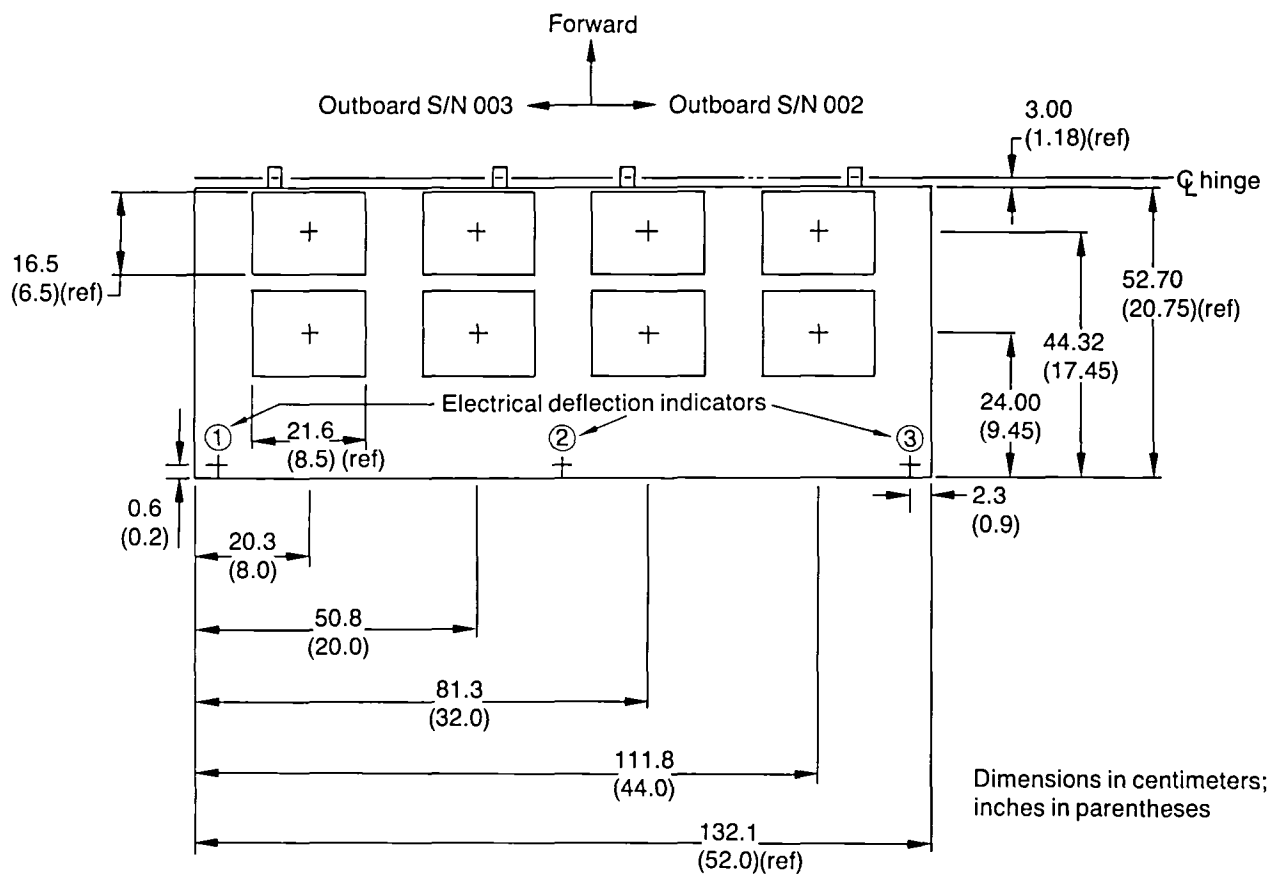


Figure 29. Location of Load Pads and Electrical Deflection Indicators Used for Design Limit Load Tests

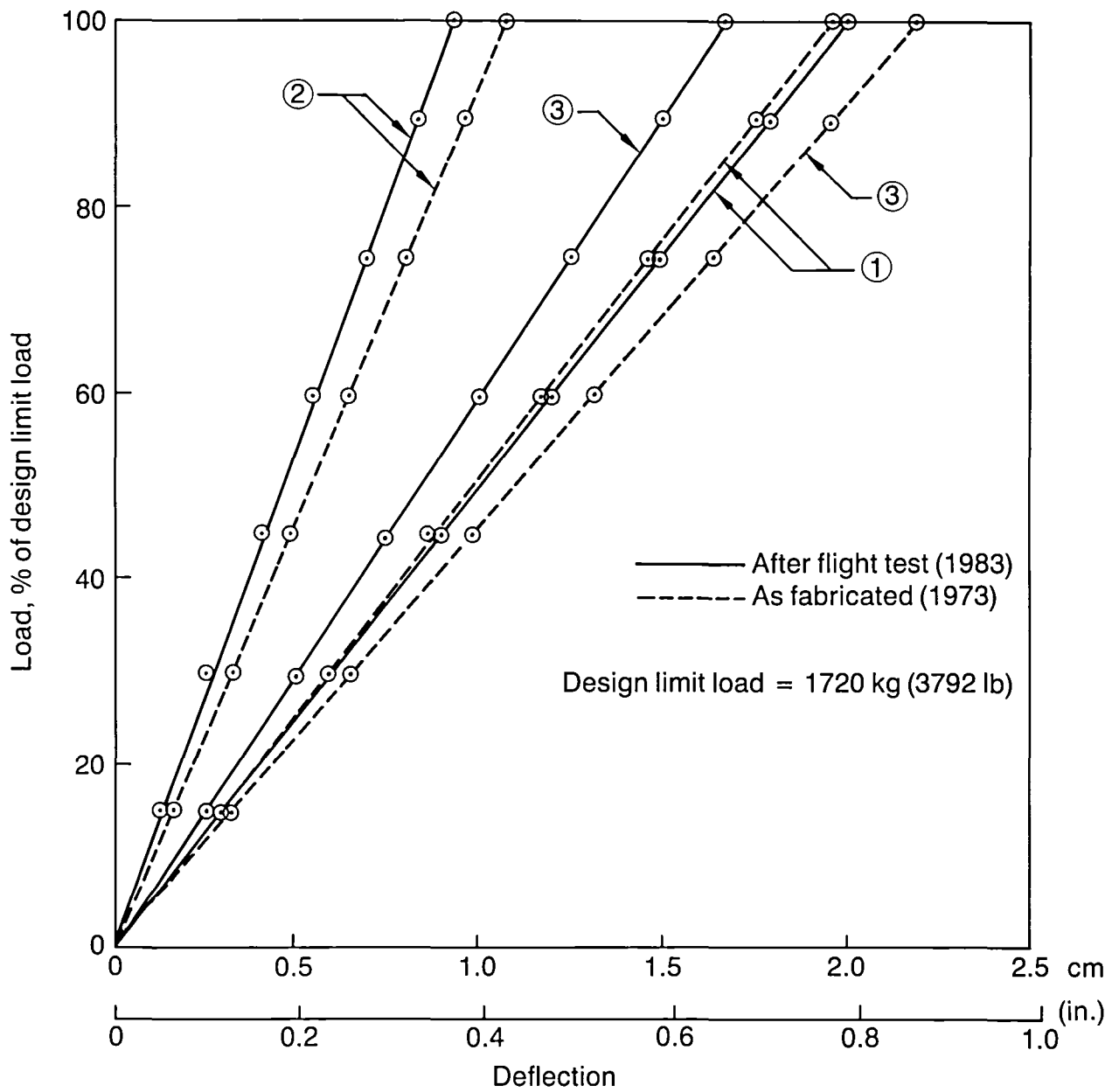


Figure 30. Deflection Measurements of Spoiler S/N 002 Before and After Flight Service as a Function of Percentage of Design Limit Load

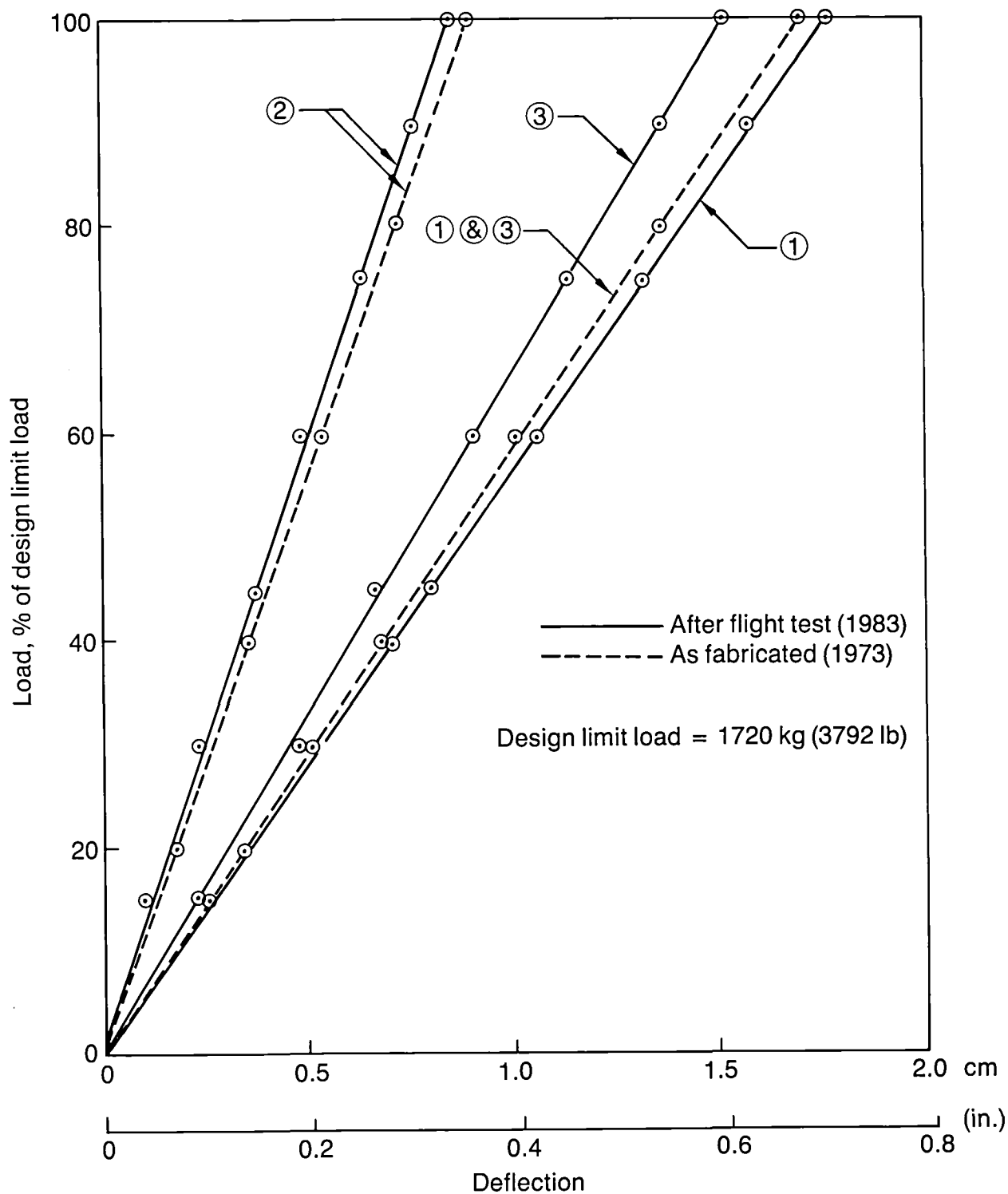


Figure 31. Deflection Measurements of Spoiler S/N 003 Before and After Flight Service as a Function of Percentage of Design Limit Load

5.0 DISCUSSION

The most interesting results of this program were the voids detected by pulse-echo ultrasonic C-scans. The large internal void in spoiler S/N 002 did not appear to grow during 8 years of flight service, nor after the application of 100% design limit load after flight service. This speaks very well of the durability and damage tolerance of aluminum-brazed titanium honeycomb structure. A much smaller void in the SS 2-20 core on spoiler S/N 003 (Fig. 20) appeared to approximately double in size during the flight service. Removal of this defect (and others) for examination by visual, metallographic, and scanning electron microscopy techniques indicated that no growth of this void, or others, actually occurred.

The fact that none of these defects were detected using either the tap or eddy-current tests is of some concern. Tap testing upon final inspection following flight service did reveal the defects. Apparently, the defect locations were not tapped during the on-site inspections. This indicates that a fairly tight grid would need to be established to have a reasonable assurance of detecting defects in service by this means.

The preflight and postflight deflection measurements demonstrated that the spoilers maintained structural integrity throughout their life. The only significant difference before and after the approximately 8 years of flight service was at the outboard and inboard locations of spoilers S/N 002 and 003, respectively. In both instances, the deflections were less following the flight experience. The reason for this is not known, but it is certainly not indicative of a problem. Each spoiler was loaded to design limit load twice, and the measurements each time were within 0.25 mm (0.01 in.) of each other.

All other problems noted were superficial. The doubler delamination was resolved by using flush-head fasteners, as in the repair of spoiler S/N 003. The paint blistering and peeling created only a cosmetic problem, not a functional one. The same problem is encountered with aluminum structure. As mentioned previously, the corrosion noted on the heads of the leading-edge seal fasteners was minor.

One of the more interesting aspects of this program was the realization of the care that must be exercised to provide defect-free brazements. These parts were closely inspected and very carefully handled through all phases of manufacture. Even with this care, defects were produced due to contaminants entrapped within double cell walls and core crushing.

6.0 CONCLUSIONS

The approximately 8 years' flight experience of the two 737 flight spoilers was successful. Spoiler deflection measurements obtained from electrical deflection indicators showed no structural degradation of either spoiler when loaded to 100% design limit load. This is very significant in light of the large braze defect found in spoiler S/N 002. This void was about 15.9 cm (6.25 in.) long and 6.4 cm (2.5 in.) wide at its widest point. This defect did not appear to grow during the 8 years of flight experience plus the imposition of 100% design limit load two times. There were areas on spoiler S/N 003 where disbonds of the exterior SS 2-20 core were present, but there was no evidence of corrosion.

A void was observed in spoiler S/N 003 that appeared to grow significantly between 1973 and 1983. Inspection of this defect, however, indicated that no growth occurred—the defect was present from the date of manufacture at its given size. The apparent growth in size of the defect between 1973 and 1983 is ascribed to differences in ultrasonic technique and/or equipment.

No signs of deterioration were observed on these spoilers that would not be observed on similar structure made by more conventional means. This includes paint blistering and peeling due to Skydrol, paint scraped off due to abrasion, minor corrosion on steel fasteners, and fabric wear.

The analysis indicates that the spoilers could be resealed and put back into service.

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16. Abstract <p>This program concluded the long-term flight service evaluation of two aluminum-brazed titanium (ABTi) honeycomb flight spoilers. The two spoilers had about 7.5 years of commercial flight experience on All Nippon Airways Model 737 aircraft. All Nippon Airways was selected because Japan has one of the most severe marine-industrial environments in the world.</p> <p>The results indicated that both flight spoilers still had the same load-carrying capability as when they were originally installed. No direct evidence of any corrosion was observed on either spoiler. Another significant accomplishment of this effort was the development of a braze design for efficiently distributing point loads from the fittings and skin into the honeycomb core.</p>			
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